

Hake and Euphausiid Acoustic Studies in the Strait of Georgia

Stephen Romaine

Fisheries and Oceans Canada, Institute of Ocean Sciences

Ken Cooke, Robert Kieser, Sandy McFarlane and Mark Saunders

Fisheries and Oceans Canada, Pacific Biological Station

Abstract

Hydroacoustics is an efficient method used to measure biological distributions and biomass within a semi-enclosed body of water, such as the Strait of Georgia. Euphausiids or krill are a major food source for several commercially important finfish, including Pacific hake (*Merluccius productus*) found within the Strait. Our surveys employed the use of a dual-frequency (38, 120 kHz) echosounding system to measure the distribution of euphausiids and hake within the Strait in the spring and summer of 2000. Survey lines were spaced approximately 5 nm apart, allowing detailed spatial interpolation (contour mapping) of the data. Surveys were complemented with net trawls for both species at several selected locations. These net trawls also served as a truthing and calibration value for our acoustic data.

Young hake (<3 years) within the Strait feed primarily on euphausiids and their spatial distributions are often related to the local euphausiid distributions. The horizontal distributions of the euphausiids are based primarily on tidal cycles and currents since the animals travel vertically to the surface to feed at night. Stomach content analysis indicate that young hake feed primarily in the morning as the euphausiids migrate from the surface feeding layers to twilight depths (about 75-125 m) to avoid predation from fish during daylight hours.

Introduction

The use of acoustics allows high-speed and detailed surveys of a study area within a limited duration of time. Our study populations vary spatially and, as such, acoustic surveys allow us to cover most areas within the Strait of Georgia. Echosounder surveys also provide an attractive alternative to net sampling since they offer more complete spatial coverage per unit cost and are minimally affected by sensor avoidance. The major drawback to an exclusive acoustics-sampling program is that no real samples are taken to truth the acoustic data. Target strength values of the study species may be well known, but different models exist to accommodate direction and orientation of fish and the assumed size of their air bladder to the acoustic return. Euphausiid target strength models account for small-scale variations and differences as small as a few mm in body length can dramatically change stock estimates.

Euphausiid Studies

Euphausiids are a spatially and temporally dynamic species and undergo diurnal vertical migration patterns: rising to feed on phytoplankton and microzooplankton near the surface during darkness and retreating to twilight depths of 75-150 m during daylight hours to avoid visual detection by predators (Mauchline, 1980). In addition, euphausiids form extremely patchy horizontal distributions with a large fraction of their total population biomass aggregated in a small fraction of the available habitat. Tidal motions, currents, light levels, interspecific competition with other zooplankton (primarily amphipods), and predators within the Strait influence their horizontal distributions. The added effect of the diurnal vertical migration patterns causes aggregations of euphausiids to form and dissipate on a daily basis.

The Institute of Ocean Sciences (IOS) has been conducting euphausiid acoustic surveys since 1990. Typically two surveys would bracket the before and after euphausiid fishery season (November – January), with possibly one additional survey conducted during the summer months to assess the current year's recruitment. The dominant euphausiid found in the Strait of Georgia is *Euphausia pacifica*, with an average body length of 16 mm and an average life span of 12-14 months. Euphausiids are one of the most abundant plankton in the Strait and form the primary food source for many commercially important fish species (e.g.,

salmon, herring, and hake). Most of the commercial fishing effort occurs in the Jervis Inlet and adjacent Malaspina Strait areas of the Strait of Georgia (about 37% of the total allowable quota), with an additional 57% of the quota split between two northern Strait inlets: Knight and Bute (Fisheries and Oceans Canada, 2000).

Surveys were conducted between 1990-1997 in two inlets adjacent to the Strait of Georgia: Saanich Inlet, located just north of Victoria, and Jervis Inlet, located on the mainland and east of Texada Island (Figure 1). Jervis Inlet was the focus of an intensive survey conducted between 1994-1996 to monitor the monthly euphausiid population dynamics and to evaluate new interpolation techniques for stock assessment purposes. Since 1997, IOS has applied these inlet methods to survey the Strait of Georgia.

Hake Studies

Pacific hake (*Merluccius productus*) form a major component of the resident fish biomass within the Strait of Georgia. Hake acoustic and trawl surveys within the Strait of Georgia and its adjacent inlets have been conducted by the Pacific Biological Station (PBS) since the early 1980s. Pacific hake have a strong tendency to aggregate in schools and areas characterised by deep basins. Younger and immature hake (0-2 year olds; 14-35 cm fork length) tend to coexist in the euphausiid layer (75-125m), whereas the older, mature hake are restricted to the deeper basins of the Strait between late February and May during the spawning season. After spring, mature hake tend to be dispersed to the western and northern areas of the central Strait, but often prefer the deeper waters (>150m) compared to the immature hake (McFarlane and Beamish, 1985). The commercial fishery operates within the Strait between late March and April and averages 5000 t·year⁻¹.

PBS has been running surveys at least once per year since 1995 and these surveys are often conducted in the early spring during the spawning season when mature hake are aggregated in the deep basins of the Strait. Different echosounding systems have been used over the last two decades, but now a dual-frequency Simrad system is currently being used to collect both fish and plankton acoustic backscatter data simultaneously, thus leading to the combined efforts of both IOS plankton and PBS hake researchers.

Combined Studies

Starting in April 2000, a combined effort was initiated to link a number of oceanographic and biological parameters to account for the euphausiid-hake interactions within the Strait of Georgia. Stomach content analysis noted that hake within the Strait feed primarily on euphausiids (over 98% of stomach content analysis), and as such, the dynamics of the local euphausiid population may affect the distributions and general health of the hake population. This paper will focus primarily on the methods and results found during the two surveys in 2000 conducted aboard the fisheries research vessel *W.E. Ricker*.

Methods

Survey Design

The Strait of Georgia is a semi-enclosed marine basin averaging about 222 km long by 28 km wide with a mean depth of about 155 m and a maximum depth of 420 m (Thomson, 1981). Euphausiid populations tend to be more concentrated in the northern areas of the central Strait, from Parksville north to Campbell River (Figure 1). During spawning season, hake tend to aggregate in two distinct basins within the central Strait, within the larger basin found between Nanaimo and Vancouver and the small basin between Courtney and Campbell River. Hake in the post-spawning season disperse to the north and west sides of the Strait.

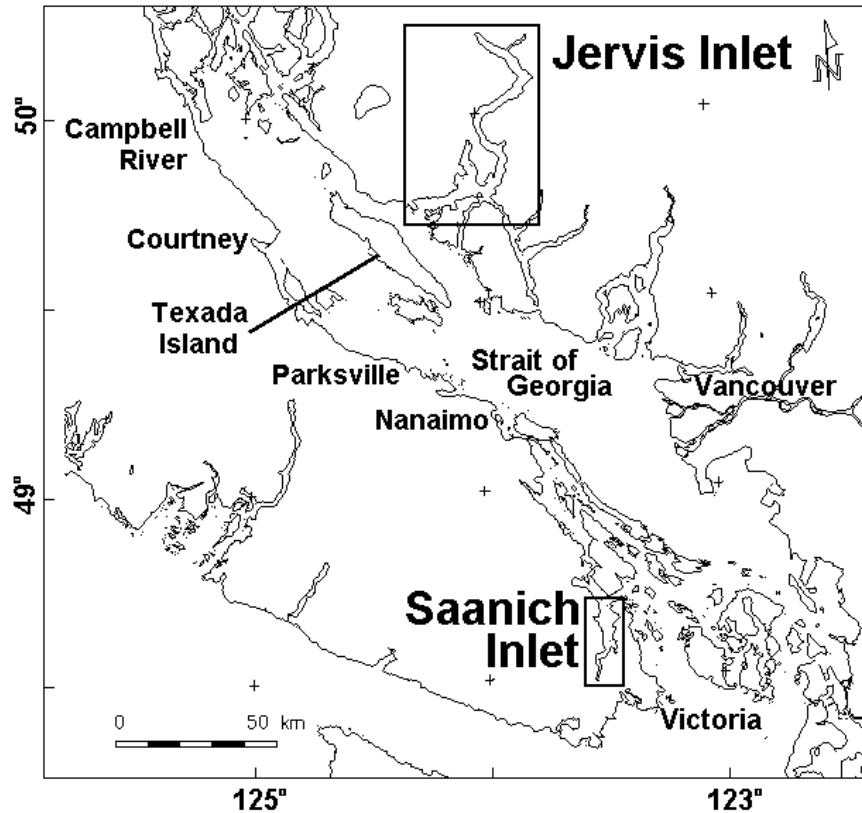


Figure 1. Combined hake and euphausiid study area. Pre-1997 euphausiid studies were conducted in Saanich and Jervis inlets. Combined hake and euphausiid studies focused on the central Strait of Georgia from Campbell River south to about Saanich Inlet.

The basic central Strait survey design used regularly spaced parallel transects that cross perpendicular to the long axis of the Strait. Nominal spacing was 3 nm and transects were terminated at the 30 m isobath or 0.5 nm from shore. This parallel transect design has remained constant over the years for hake surveys within the central Strait. The addition of combined inlet surveys has dictated a similar design to the IOS euphausiid surveys that use zigzag patterns (Figure 2; see Romaine, 1997 and Romaine and others in press) due to the narrow spacing of the inlets. Surveys conducted between Texada Island and the mainland also required the use of zigzag transects. The choice of transect designs depends on both the bathymetry of the area and the patterns of the target species. The use of regularly-spaced, cross-axis transects permits the sampling of hake across the basin regions of the Strait. The drawback of this method is that survey time is lost from the end of one transect to the beginning of the next. Zigzag transects minimize lost survey time; however, they may not representatively sample biological populations that are primarily confined by isobaths or basins.

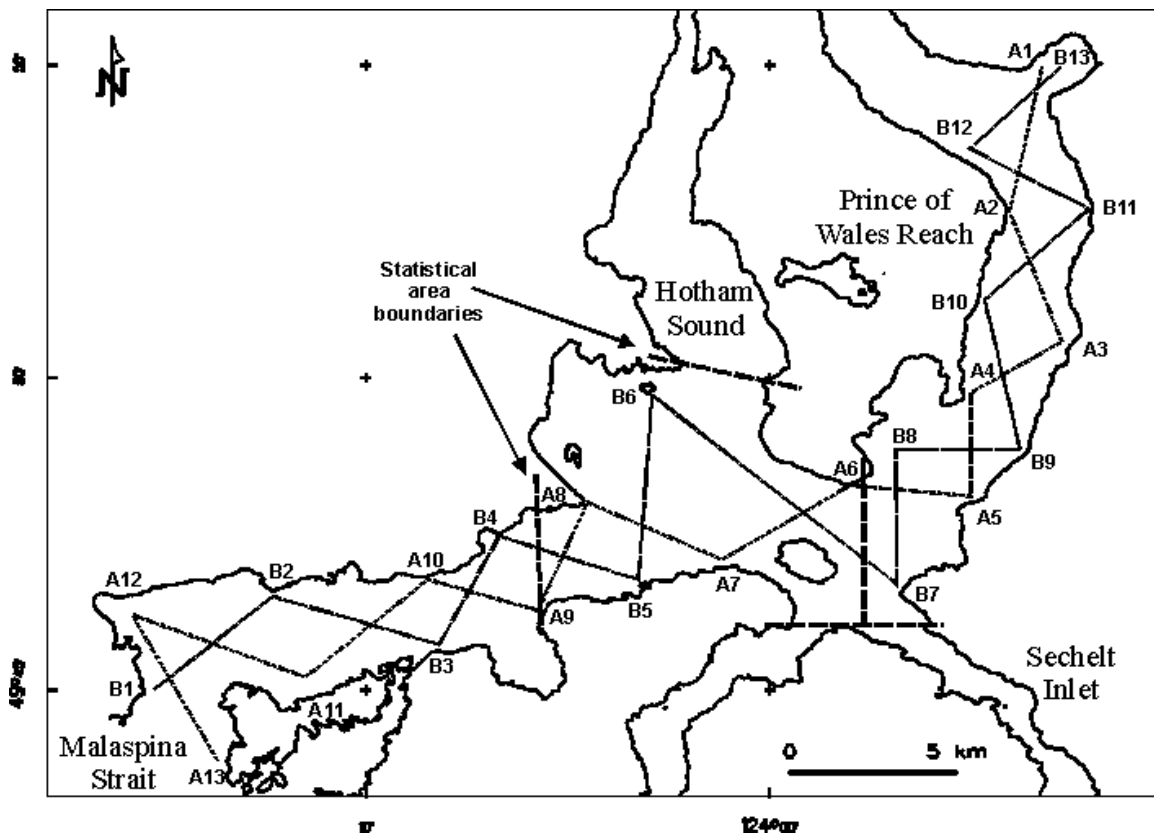


Figure 2. Jervis Inlet zig-zag acoustical transects. Two mirror-image transects were used between the mouth of the inlet (waypoints A13 and B1) and Vancouver Bay (waypoints A1 and B13). Transects provided detailed accounts of the small-scale variations of euphausiid distributions within the main

Biological Sampling

Fishing activities were conducted to confirm species composition and to truth our acoustic samples. Hake trawls were conducted on both the shallow (75-125 m) and deep (150-400 m) layers using a Canadian Diamond 5 midwater trawl with a 6 m vertical mouth opening and a 3 cm herring codend. For typical catches at least three tubs of hake from the start, middle and end of the hopper load were selected for routine biological sampling. This included length, sex, maturity, and stomach contents (Weir and others 1978).

Plankton were sampled with a Tucker Trawl, outfitted with three 235 μ m nets targeting the euphausiid layer observed on the acoustics system (usually between 75-150 m). Only the middle net was of interest and it was opened at the bottom and closed at the top of the scattering layer. Samples were volume-reduced and preserved in a 3.7% formaldehyde solution for subsequent analysis.

Plankton samples from both Tucker Trawl and hake stomachs were sub-sampled to about 120 animals using a sieve splitting technique prior to analysis. Each animal then had its species, sex, length, and digested state (for stomach contents) recorded. For highly digested animals, the nearest positive identification was recorded.

Acoustic Systems

Surveys conducted during 2000 used a Simrad EK500 dual-frequency, split-beam acoustic system (Kieser and others 1998) with both the 38 and 120 kHz transducers mounted on a single retractable ram located near midship at keel depth (~4.3 m). All survey work was conducted with the ram fully extended. The EK500 echosounder was connected via a LAN to a PC with SonarData's Echoview software that was used

to log acoustic, navigational and GPS data, and to store parameter files. Using both the 38 kHz and 120 kHz frequencies allowed the collection of both fish and plankton data simultaneously.

Subsequent acoustic data processing used Echoview to define and integrate over the layers to produce an averaged estimate of biomass per 150 m²-1 km². Net tow data collected in the same area were used to verify acoustic returns and to provide histograms of population distributions. In some historical sets, pollock were present and may have accounted for a small proportion of the total scattering layer; however, pollock numbers during the 2000 surveys were negligible to be accounted for during the integration process. For plankton tows, species were identified and non-euphausiids (primarily amphipods and pteropods) were accounted for in the acoustic integration to provide only an estimate of the euphausiids within the scattering layer.

Our EK500 was calibrated using a set of calibration spheres and the procedures outlined in Foote and others (1987a, 1987b) and in the EK500 operations manual (Simrad 1993). A target with well-known acoustic properties was suspended under the vessel in the acoustic beam using a customized target calibration system developed at IOS. Advantages of a standard target calibration are that the acoustic system remains on the vessel, that measurements are made under conditions that are nearly identical to those used during the survey, and that the calibration can be repeated as needed. A calibration was performed for both of our surveys in April and October 2000.

Integration

Hake biomass was first plotted along parallel transects as 'porcupine plots' (Figure 3). Integration was conducted by treating each parallel transect as an average block of data and a proximal analysis was used for its simplicity and robustness (Kieser and Langford 1991; Cooke and others 1992; Kieser and others 1995). An average biomass was then determined for each parallel transect by using a masking technique to delineate the survey area (see Kieser and others 1999).

Euphausiid biomass interpolation used semi-variogram models to assess the degree of autocorrelation between nearby samples. Although this technique is more suited for zigzag transects, it was applied here to reduce error bars on stock estimates, and to give a better resolution of the spatial distribution of the euphausiid populations. Variowin 2.2 (Pannatier, 1996) was used to generate semi-variogram models for the central Strait, and these models were passed to the interpolation functions in Surfer 7.0. The geostatistical method of kriging was used to interpolate the results (see Romaine and others in press).

Target Strength Considerations

The drawback of acoustic surveys is the parameter of biomass estimation from echo return. Various authors use different accepted target strength (TS) values to determine the biomass of fish from the echo integration. Several other factors, such as orientation and angle of the fish relative to the insonifying pulse, complicate the overall estimate of biomass (see Macaulay 1994 for a further discussion).

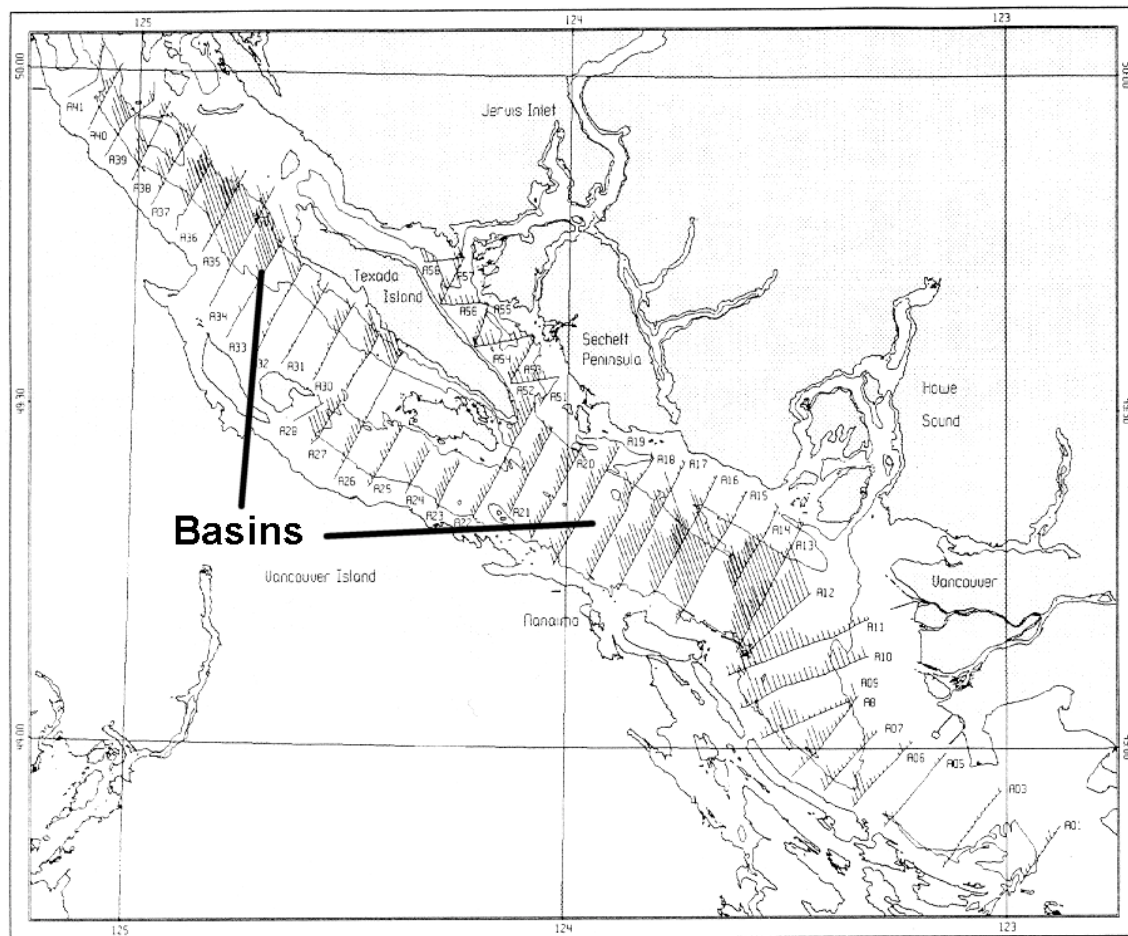


Figure 3. Porcupine plots of hake biomass, 1996. Shown are the deep basins where biomass values tend to be higher during spring spawning season.

Use of the 38 kHz to detect hake required an adaptation of a TS value of $-35 \text{ dB} \cdot \text{Kg}^{-1}$ fish weight to generate consistent results with researchers from the US NMFS who have been using this value for their offshore hake biomass estimates. Various TS literature reviews (Taylor and Keiser 1982; Kieser 1983; Kieser and others 1998) were used to obtain an appropriate TS length relation that was then converted into a weight regression using coefficients obtained from McFarlane and Beamish (1985). See Kieser and others 1999 for a full discussion of TS values used in the Strait of Georgia hake-sampling program.

Plankton detection using 120 kHz was first subjected to a truthing of the scattering layer by a series of Tucker Trawls conducted immediately following most hake sets. Often the target scattering layer contained near 100% euphausiids, but on occasion, other scatters were found to be present in the layer, therefore requiring the acoustic scattering biomass estimate to be reduced by a percentage to account for the non-euphausiid components.

Our euphausiid TS values used the model proposed by Macaulay (1994). Various euphausiid TS models were available, but this model has been used since the mid-1990s in the Strait of Georgia and adjacent inlets for euphausiid surveys conducted by private industry (Romaine 1995), the Pacific Biological Station (R. Beamish and I. Pearsall pers. comm.), and the Institute of Ocean Sciences. Histograms of size-frequency were used to assess the return TS values from acoustic samples taken by nearby Tucker Trawl samples. Changes in dB values with length of euphausiids vary, yielding poor results when an average

euphausiid length is assumed for the study area. Therefore, the frequency distribution was applied as a percentage to the expected TS return using the Macaulay model (see Romaine 1997 for further discussion on these modifications).

Results

Euphausiid Studies

Previous surveys in Jervis Inlet used a series of zigzag transects to develop methods for use in the Strait of Georgia starting in 1997. Use of the zigzag mirror transects allowed us to determine the trade-offs between intensely and sparsely surveyed transects using geostatistics. Additionally, this information would give us an idea of the day-to-day dynamics of the euphausiid patches within the inlet. Using monthly survey data from 1994 to 1996 collected along the 'A' and 'B' transects in Jervis Inlet (Figure 2), we determined both the variability between each transect and the variability between combined transects collected on subsequent days. For individual transects, we found that individual transects collected over a one-day period varied by an average of 48%. For combined transects compared between days, this variability was reduced to 29% (Romaine and others in press).

Kriged values also provide detailed contour maps of distributions and biomass estimates from interpolated data, along with the confidence intervals for those estimates. Unless there are very few sample points or no autocorrelation within the data set, kriged values will always give smaller error bars on biomass estimates over the traditional method of averaged biomass and the determination of error bars from the variance. Figure 4 shows a sample distribution for euphausiid estimates from Jervis Inlet in June 1995 and along with this estimate, the degree of error is given by the kriging confidence intervals.

Kriged interpolated values from the combined hake and euphausiid studies are given only for the central Strait of Georgia. April 2000 values were estimated at $914\,200 \pm 51\,500$ t (wet weight) and August 2000 were estimated at $1\,162\,400 \pm 11\,200$ t. Figure 5 displays the August 2000 euphausiid distributions for the central Strait. Euphausiid values during 2000 were among the highest recorded concentrations over the last decade. The combination of different surveys collected by both IOS and PBS between the years 1997-2000 and correcting for different TS models and survey areas indicated that the 2000 estimate of euphausiid values is almost double that of 1999 (Figure 6). *Vector* and *Tully* surveys were conducted by IOS using a 100 kHz sounder; surveys collected by PBS used the fishing vessel *Krillseeker*, which was outfitted with a 200 kHz sounder.

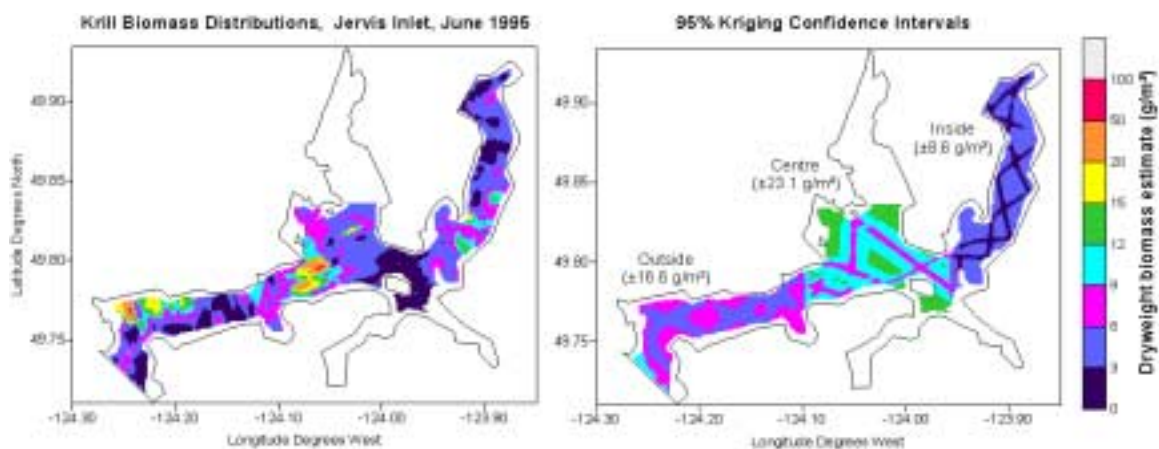


Figure 4. Jervis Inlet euphausiid biomass estimates from June 1996. Left: euphausiid distributions and biomass estimate using kriging. Right: kriged 95% confidence intervals on the interpolated results and the average error for each of Jervis' sub-regions.

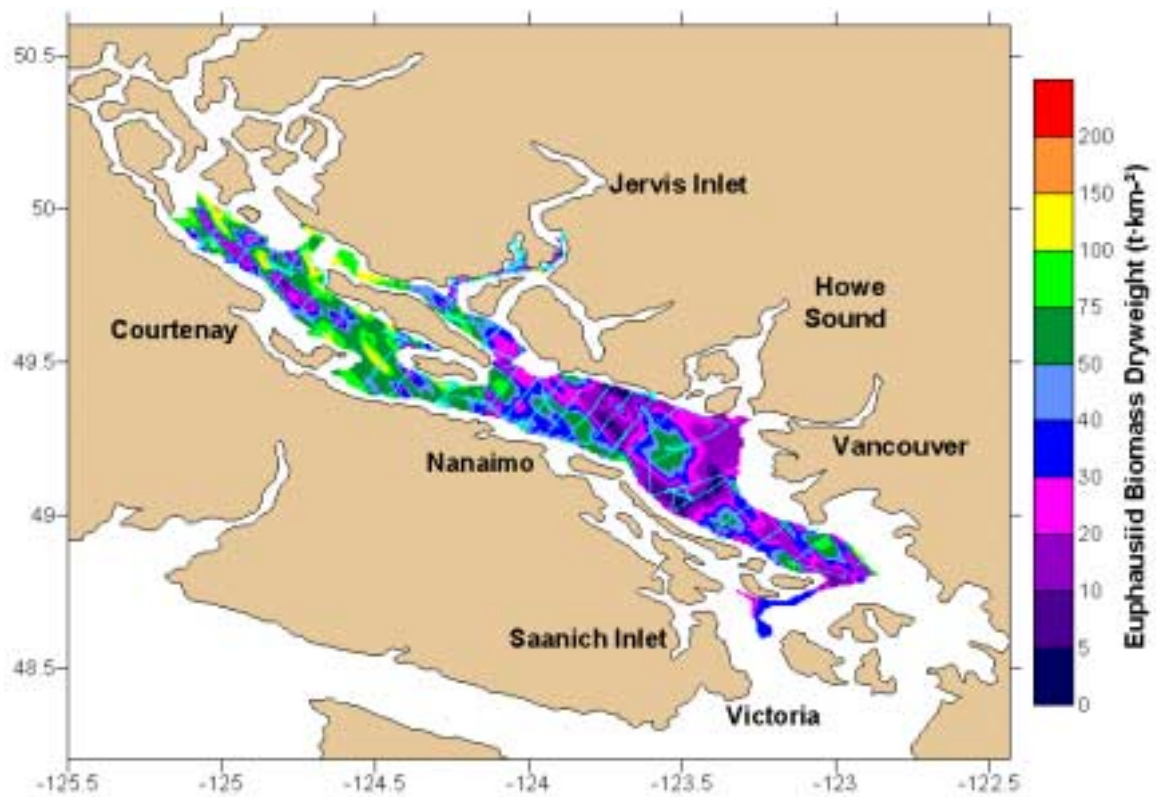


Figure 5. Central Strait of Georgia euphausiid distributions for August 2000. Total biomass was estimated at $1\,162\,400 \pm 112\,000$ t wet weight.

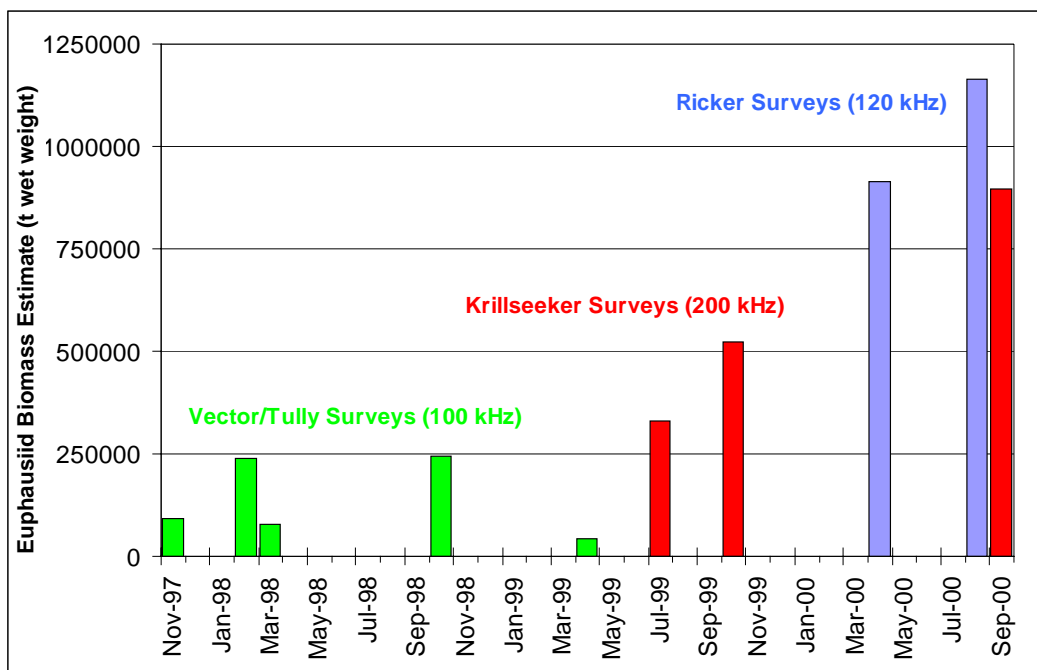


Figure 6. Euphausiid biomass estimates for the central Strait from 1997-2000. Different platforms and equipment were used to collect data and these have been standardized to compare biomass estimates.

Hake Studies

Hake studies conducted in the last few years have shown a current biomass in the order of about 50,000 t. While there has been a strong recruitment through the 1990's, mature (>2 year old) hake are declining in size-at-age (Figure 7). An average four-year-old hake's fork length is about 35 cm within the Strait, compared to 40 cm a decade ago. The smaller and immature hake have remained at a constant size over the last two decades, but the older hake appear to be experiencing a decline in size-at-age.

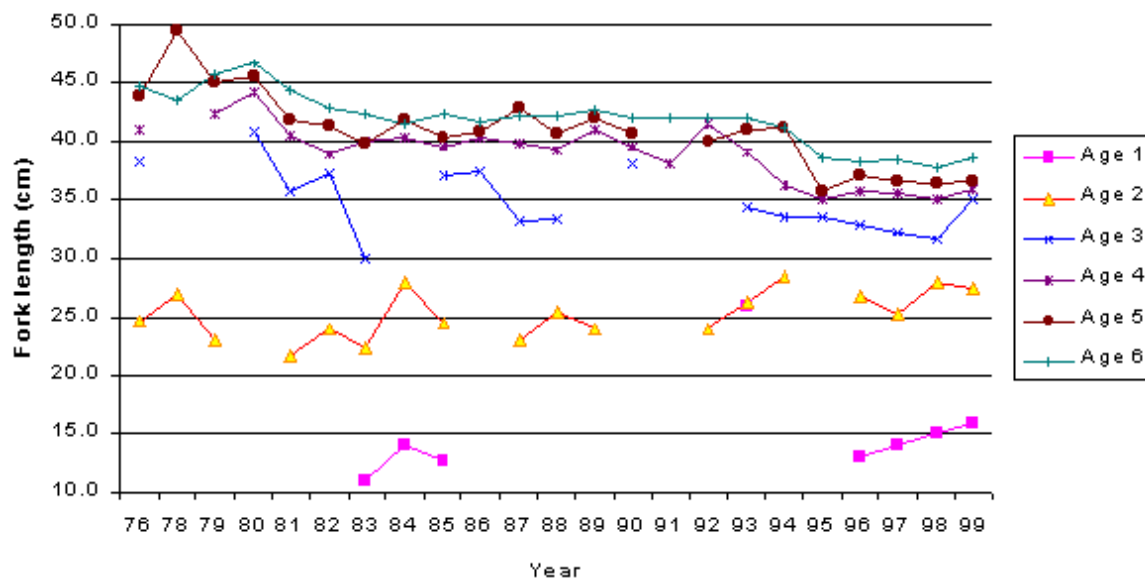


Figure 7. Mean size of female hake within the Strait of Georgia from 1976-1999. Mature hake (3+ year olds) are declining in size-at-age, whereas immature hake are maintaining their sizes.

Stomach content analysis of hake captured within the Strait observed that the immature hake were feeding almost exclusively (over 99% stomach contents) on euphausiids, when euphausiids were present in any concentration. When euphausiids were not present within the scattering layer, immature hake fed on an assortment of amphipods (tows just north of Nanaimo) or Galatheididae crab larvae (tows in Howe Sound). Hake tend to feed in the morning hours as the light levels increase and the euphausiids return to the twilight depths from the surface. The freshest stomach content samples were always collected on the first morning tow (around 07.00) and nearly completely digested samples (only euphausiid eyeballs and mush remaining) were found by early afternoon. We suspect that immature hake also feed in the evening on euphausiids returning to the surface, however no night sets were made.

Mature hake from the deeper (125-400 m) scattering layers were found almost exclusively to have empty stomachs. Recovery of trawl equipment from this depth either caused the stomach contents to be purged or the entire stomach to become everted and as such, it is uncertain what these deeper fish are feeding on or how abundant their prey items are.

Discussion

Hake and Euphausiid Interactions

Stomach content analysis revealed that *Euphausia pacifica* was the preferred food source for the immature hake that co-exist in the scattering layer between 75-125 m. These hake tend not to feed during the daylight hours on their co-existing prey items, likely due to darkness limiting the visual detection of euphausiids. Feeding on euphausiids occurs in the morning hours as the euphausiids return from the surface to the twilight depths; the euphausiids are fully emaciated within about six to eight hours.

Two combined hake and plankton trawl stations indicated that these immature hake feed alternatively on other plankton sources when euphausiids are not available. In the military exercise area 'Whisky-Gulf', located between Nanaimo and Parksville, there has been an exclusion of euphausiids from the scattering layer noted in surveys conducted over the last decade by IOS. The reasons why gammarid and hyperid amphipods exist and displace euphausiids in the 75-125 m water column range are unknown; hake in this

area feed on a mix of amphipod species. In Howe Sound, a relatively faint scattering layer of euphausiids was identified in April 2000 and hake in this area were feeding on Galatheidæ crab megalops. Despite the food source, immature hake seem to be obtaining food sources and are not being starved.

Stomach contents of mature hake are difficult to obtain as a majority of the fish either had no stomach contents (lost during recovery?) or everted stomachs; either way we are unsure what these hake are feeding on and in what concentrations. Hake distributions in some of the northern Strait inlets (e.g., Bute and Knight inlets) were distinctly different than those found in the Strait. Trawls conducted in Bute inlet during April 2000 noted mature hake exist in the upper scattering layer and feed on a combination of both glass shrimp (*Pasiphaea* sp.) and *Thysanoessa* sp. (a different euphausiid species). Captured hake were well fed and were much larger in their size-at-age compared to their Strait of Georgia counterparts.

Are Strait of Georgia mature hake decreasing in size-at-age due to a reduction in food or is there a density-dependence issue? The shallower, immature hake are feeding and growing at similar rates to those found two decades ago, whereas the older hake are declining in size-at-age. Hake found in some of the northern Strait inlets indicate that in the presence of abundant food sources, their sizes are comparable to those found in the Strait two decades ago. Acoustic surveys conducted in 2000 within the Strait indicate that euphausiids—the preferred hake food source—are at their highest concentrations in over a decade.

Acoustic Considerations

Acoustics provide a much more detailed account of the population dynamics of a species than net tows alone, but the disadvantage of this method is that no real samples are collected during acoustic transects. Collection with trawl gear for both fish and plankton allowed truthing of our acoustic samples to our net tows and these captures provided size-frequency distributions, sex ratios, and ages of the fish and species and size-frequencies for the plankton. Target strength parameters allow the translation of acoustic backscatter into biomass so that stock assessments may be made on the population in question. The problem with TS parameters is that variations between authors, fish species, orientation, and interferences from other targets within the water column can affect biomass estimates. We have used consistent TS models for both our hake and plankton data to minimize problems; further research, however into the target strengths produced by our local species will ensure better estimates are made.

Interferences were minimized with the use of two different frequencies on our echosounding system; however, as immature hake and euphausiids tend to coexist in the upper scattering layer, there remains the issue of target separation to avoid biasing during layer integration. Often, non-planktonic targets found in the 120 kHz scattering layer are easily visualized and can be excluded on the echogram prior to interpolation of the layer. More difficulties occur when dense layers of plankton exist and are detected on the 38 kHz scattering layer, interfering with the integration of the hake layers. In both cases, fish and plankton can be visually separated; this however, becomes a labour-intensive process and the usual default is to term small sections as ‘bad data’, excluding them from integration. When large stretches along transects have this plankton/fish-mixing problem, this is not an option. We are currently investigating methods that allow the separation of the plankton and fish signals using algorithms that filter through both echosounder frequencies. Combining these efforts with the establishment of a database of expected target strength values for both euphausiids and hake will allow us to reduce potential sources of bias and error in our stock assessment estimates.

Acknowledgements

Funding for monthly euphausiid acoustic sampling in Jervis Inlet was obtained from a NRC-IRAP program using the F/V *Krillseeker* from June 1994 to June 1995. Private funding from Biozyme Systems (Vancouver, B.C.) provided an additional *Krillseeker* survey in February 1996. PBS and IOS acoustic programs were funded from various Fisheries and Oceans Canada sources. Thanks are given to all the scientists and technicians involved in the 2000 surveys (G. Jewsbury, D. Tzotzos, M. Surry, B. Andrews, L. MacDougall, R. Tanasichuk, and R. Campbell), the officers and crew of the *W.E. Ricker*, those involved in the data processing (D. Moore and M. Galbraith) and to B. Wai for her reviews and suggestions to this manuscript.

References

- Cooke, K., R. Kieser, M. Saunders, W.T. Andrews, and M.S. Smith. 1992. A hydroacoustic survey of Pacific hake on the continental shelf off British Columbia from the Canada/U.S. boundary to Queen Charlotte Sound: August 13-28, 1991. Can. Man. Rep. Fish. Aquat. Sci. 2174:40 pp.
- Fisheries and Oceans Canada. 2000. Pacific region 2000 & 2001 multi-year management plan: euphausiid.
- Foote, K.G., H.P. Knudsen, and G. Vestnes. 1987a. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Coop. Res. Rep. 144:70 pp.
- Foote, K.G., H.P. Knudsen, G. Vestnes, D.N. MacLennan, and E.J. Simmonds. 1987b. Calibration of acoustic instruments for fish density estimation: A practical guide. ICES Coop. Res. Rep. 144:69 pp.
- Kieser, R. 1983. Hydroacoustic biomass estimates of bathypelagic groundfish in the Georgia Strait, January, February, and April 1981. Can. Man. Rep. Fish. Aquat. Sci. 1715:84 pp.
- Kieser, R., K. Cooke., W.T. Andrews, G.A. McFarlane, and M.S. Smith. 1998. A hydroacoustic survey of Pacific hake in the Strait of Georgia, British Columbia, Canada, February 20-March 5, 1996. Can. Man. Rep. Fish. Aquat. Sci. 2456:57 pp.
- Kieser, R. and G. Langford. 1991. An application of spatial analysis to fisheries acoustics. Proc. GIS'91 Symp., Vancouver, B.C. February 1991. p. 335-339.
- Kieser, R, G. Langford, and K. Cooke. 1995. Use of a geographic information system for the display and analysis of fisheries acoustic data. Presented at the symposium for fisheries and plankton acoustics, Aberdeen, Scotland, June 12-16, 1995. Paper No. 190:12 pp.
- Kieser, R., M.W. Saunders and K. Cooke. 1999. Review of hydroacoustic methodology and Pacific hake biomass estimates for the Strait of Georgia, 1981 to 1998. Can. Stock. Assess. Secr. Res. Doc. 99/15:53 pp.
- Macaulay, M.C. 1994. A generalized target strength model for euphausiids, with applications to other zooplankton. J. Acoust. Soc. Am. 95(5):2452-2466.
- Mauchline, J. 1980. The biology of mysids and euphausiids. Adv. Mar. Biol. 18:371-678.
- McFarlane, G.A., and R.J. Beamish. 1985. Biology and fishery of Pacific Whiting, *Merluccius productus*, in the Strait of Georgia. Mar. Fish. Rev. 47(2):23-34
- Pannatier, Y. 1996. VARIOWIN 2.2: Software for Spatial Data Analysis in 2D, Springer-Verlag, New York, NY.
- Romaine, S.J. 1995. Jervis Inlet bioacoustic euphausiid biomass determination: 1994-1995. Report for Seasource Systems, Inc.
- Romaine, S.J. 1997. Estimation of krill (*Euphausia pacifica* Hansen) biomass within semi-enclosed bodies of water. M.Sc. Thesis, Univ. Victoria. 144 pp.
- Romaine, S.J., D.L. Mackas, and M.C. Macaulay. In Press. Comparison of euphausiid population size estimates obtained using replicated acoustic surveys of coastal inlets and block average vs. geostatistical spatial interpolation methods. Submitted to Fish. Oceanogr.

Romaine and others: *Hake and Euphausiid Acoustic Studies in the Strait of Georgia*

- Simrad. 1993. Simrad EK500 scientific echo sounder reference manuals V4.01. Simrad Subsea A/S, Strandpromenenaden 50, Box 111, N-3191 Horten, Norway.
- Taylor, F.H.C. and R. Kieser. 1982. Distribution and abundance of herring and other pelagic fish off the West Coast of Vancouver Island in September, November 1980, and March 1981, and in the Strait of Georgia in November 1980. Can. Ms. Rep. Aquat. Sci. 1682:167 pp.
- Thomson, R.E. 1981. Oceanography of the British Columbia coast. Can. Spec. Publ. Fish. Aquat. Sci. 56:291 pp.
- Weir, K.R, R.J. Beamish, M.S. Smith, and J.R. Scarsbrook. 1978. Hake and pollock study, Strait of Georgia bottom trawl cruise G.B. REED, February 25 – March 13, 1975. Fish. Mar. Serv. Data. Rep. 71:153 pp.